Project-Based Learning Methodology to Promote Essential Skills in Mechanical Engineers. A Case of Study in Structural Mechanics

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Abstract

In this study, we report our experience of applying the Project Based Learning (PBL) methodology in the subject Design and Experimental Project (DEP), a second-year subject on the Degree in Mechanical Engineering at the Universitat Rovira i Virgili (URV). It is a project-based subject that introduces students to the analysis and design of simple structures so that they can acquire a practical understanding of the main concepts of the strength of materials as applied to engineering systems. It aims to expose students for the first time to real structural engineering. With the aid of PBL methodology the subject introduces students to a set of educational tools so that they can develop essential skills by designing, constructing and testing mechanical prototypes in Structural Mechanics. The skills developed are those that we believe to be essential for success in a professional engineering context: critical thinking, complex problem solving, creativity, teamwork, time management, operation analysis, active learning, judgment and decision making, management of material resources, being innovation minded and, of course, communication. The teaching methodologies, the planning and the syllabus by which these essential skills are taught through a PBL approach are presented in detail. The results of an anonymous student satisfaction survey show that students think that this teaching methodology helps them to acquire and reinforce essential skills such as time and work management, communication and teamwork either through lectures and hands-on exercises or through each of the four projects carried out during the course. On the other hand, students think that their proficiency in skills such as management of material resources or active learning are very good but not necessarily acquired as a result of the DEP subject.

Keywords: *Project Based Learning; Soft Skills; Mechanical Engineering; Structural Mechanics;*

1. Introduction

The professional performance of mechanical engineers requires, in most situations, structured cognitive processes that lead to clear, concise and rational decisions. Some of these decisions are largely technical and are based on technical codes or standards that assist their decision-making. However, when the decisions need to take into account practical issues and the limitations imposed by safety concerns and costs, the process is much more complex. As a consequence, engineers need to have specific hard skills including technical knowledge and abilities that can be acquired through formal education and training programs. These skills can be clearly defined, evaluated and measured. But they also need to have soft skills such as strong analytical and critical thinking, leadership and communication skills. These skills are very difficult to teach, evaluate and, especially, define because the perception of what a soft skill is can depend on context. What is clear is that as well as the technical skills or requirements that are perfectly defined, our students need to develop other essential or additional skills if they are to succeed in a professional engineering context. It is therefore fundamental to introduce educational tools at university level that help to develop these skills in a practical and continuous manner. Some excellent examples of different approaches to this can be found in the literature in [1, 2].

The Degree in Mechanical Engineering (DEM) at the URV focuses on experimental and practical teaching as the way to develop students' aptitudes and abilities. Students can acquire experimental techniques in a number of practical subjects called *Design and Experimental Project* (DEP) developed specifically for each degree course.

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The main objective of these subjects is to promote essential skills in the different disciplines in which mechanical engineers can practise their profession. The aim is to change inquisitive students into inventive engineers with a view to their professional future. To this end, these DEP subjects are project-based courses that introduce tools and methods for designing and constructing (when possible) mechanical prototypes from different mechanical engineering disciplines: Statics and Dynamics of Simple Machinery (first year), Structural Mechanics (second year) and, finally, Machine Elements and Components (third year). In this study, we present our experience with the methodology of PBL in Structural Mechanics.

2. Methodology

The cornerstone of all DEP subjects is to carry out different projects in which teams of students conceive, design and construct a mechanical product. The idea underlying these subjects is to introduce the students to the essence of engineering work and the processes of designing and developing new mechanical/structural projects through experiential learning, and, at the same time to provide a clear overview of the different fields in mechanical/structural engineering. Class sessions are conducted in workshop mode and use cases and hands-on exercises to reinforce key ideas. Students are introduced to engineering and construction project-management strategies at various levels from the initial conceptual phase, through design and construction, to completion.
The DEP subject for Structural Mechanics is taught in the second semester of the second year of the DEM and preceded in the degree program by a course in Elasticity and Strength of Materials. This DEP subject introduces students to the analysis and design of simple structures so that they can acquire a practical understanding of the main concepts of material strength as applied to engineering systems. The class size is 50-60 students each academic year. Students complete 60 face-to-face teaching/learning hours in one semester (4 h/week over 15 weeks) consisting of 1 hour/week of lectures and 3 hours/week of tutorials and design project sessions. The subject is organized as follows:

Teacher-guided (TG) part (15 h): the key ideas are presented and reinforced and the projects to be carried out are presented. The theoretical content presented during the TG part largely aims to help students develop essential skills. In this part all the students attend lectures together.
Student-focused (SF) part (45 h): the students engage in hands-on exercises to reinforce the key ideas presented in the TG part, and develop their designs (thinking, searching for relevant information, writing reports, etc.). The projects carried out during the course are also experimentally evaluated in this part. The students are divided into three groups of 20-25 students.
Structural projects (SP): four SPs are proposed to the students to be designed, constructed and tested with different dimensional and structural pre-conditions. They are all scaled structural projects of increasing complexity (see Figure 1 for examples):

SP 1: truss made of canes designed to support a water tank.
SP 2: truss made of spaghetti simulating a high voltage tower.
SP 3: crane-bridge made of ice-cream sticks designed to stand vertical and lateral loads.
SP 4: bridge for a train made of rigid copper/aluminium wires.

In each SP, the students, working in small teams (3-4 students), are given 3-4 weeks to complete their design and build the prototype. They are encouraged to consult and retrieve relevant information from textbooks, internet or other sources related to each project (materials, design, construction, etc.). The project is tested in class as a competition between all the teams. They are also asked to give an oral presentation in which they have to explain their solution for the project presented. These “testing classes” are excellent opportunities for the teacher to give technical explanations about why the prototypes fail/succeed, and to point out technical concepts related to the project. At the end of each group’s oral presentation, students are encouraged to give informal feedback and evaluate their peers. Each individual group member has an individual mark awarded by the teacher and a common group mark obtained from the peer-assessment. Therefore, **the final mark** includes: an individual mark for all the hands-on exercises that makes up 30% of the total mark; a group mark for the projects (12.5% each project), which includes the teacher’s mark for the project, the written report, the oral presentation and the peer-assessment; and, finally, an individual mark for a final conceptual test (20%).

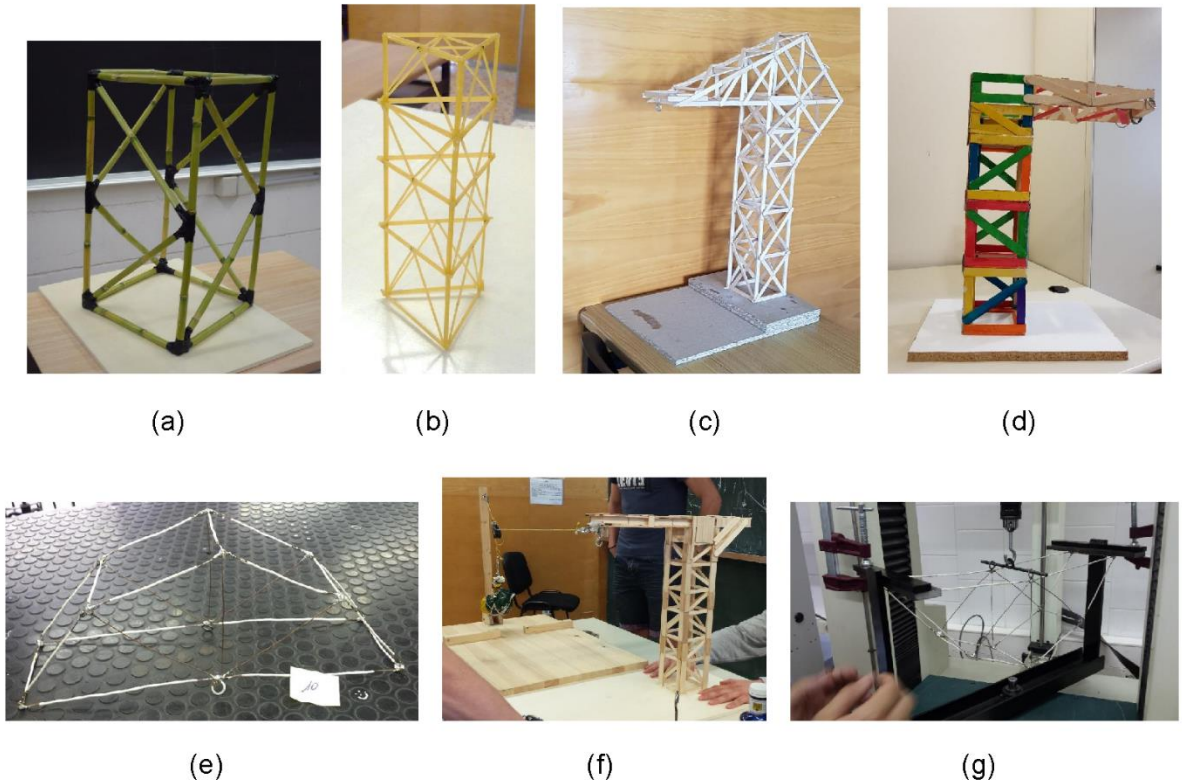

Figure 1. Examples of prototypes for: (a) SP1; (b) SP2, (c-d) SP3 and (e) SP4. (f-g) Testing these prototypes.

The syllabus of the subject was specifically developed to provide students with the main skills that are considered to be essential for a mechanical engineer (technical/hard and soft skills). These are the following: teamwork, interpersonal interaction and judgment, time/work management, communication (written/oral), creativity (versus structural projects), technical analysis and problem solving; critical thinking; judgment and decision making, active learning, management of material resources, and being innovation minded. Skills can be practised in any or all the projects (like innovation minded, critical thinking or active learning), lectures or tutorials. The schedule of the course is presented in Figure 2, which also shows the essential skills that are to be transmitted.
To determine the students' perception of the extent to which they have acquired these skills during the learning process and their satisfaction with the methodology, a survey was conducted via Moodle. The questions were divided into two categories:

- Closed questions (YES/NO) on the usefulness of our teaching methods for acquiring the essential skills.
- Questions on their own proficiency in different essential skills by the end of the course. A modified 10-point Likert scale was used (1 = no proficiency, 10 = high proficiency).
  The survey was conducted at the end of the semester. Of the 55 students enrolled in the subject in the academic year 2016-17, 52 answered the survey (3 female and 49 male). The data collected from the survey were analysed and the percentages for each question were obtained.

Week	Teacher-guided part (1 h/week)	Student-focused part (3 h/week)	Essential skills developed in TG/SF
1	Presentation of the subject: course description, grading and schedule. **Presentation of SP1.**	Creating the work teams. "How to work in teams effectively" and "Good time management enables you to work smarter". Practical session and hands-on exercises on both topics.	Teamwork /Time (and work) management.
2-3	How to write an engineering report.	Working on SP1. Hands-on exercises for engineering report.	Communication (written)/ management of material resources
4	How to make oral presentations	**Evaluating & Oral presentation SP1** (as this is the first oral presentation, this session focuses on the strengths and weaknesses of each group)	Communication (oral) /interpersonal interaction & judgment (assessment of other teams)
5	How to look effectively for technical useful information. Presentation of SP2		
6-7	Selecting engineering materials. Modern materials.	Hands-on exercises for Selecting engineering materials. Working on SP2.	Technical analysis & problem solving/ judgment & decision making/ innovation minded
8	Intuitive design of trusses and frames (1/2). Presentation of SP3.	**Oral presentation & Evaluating SP2**	Communication/interpersonal interaction & judgment (assessment of other teams)
9	Intuitive design of trusses and frames (2/2).	Hands-on exercises of Intuitive design of trusses and frames. Working on SP3.	Creativity/ Technical analysis & Problem solving / judgment & decision making
10-11	Intuitive design of beams, porches and arcs.	Working on SP3. Hands-on exercises of Intuitive design of beams, porches and arcs.	Creativity/ Technical analysis & Problem solving / judgment & decision making
12	Structural problems in industrial buildings (1/2). Presentation of SP4.	**Oral presentation & Evaluating Project 3**	Communication/interpersonal interaction & judgment (assessment of other teams)
13-14	Structural problems in industrial buildings (2/2).	Working on SP4. Hands-on exercises of Structural problems in industrial buildings.	Technical analysis & Problem solving / judgment & decision making/ technical analysis
15	Final conclusions and remarks on the subject	**Oral presentation & Evaluating Project 4**	Communication/interpersonal interaction & judgment (assessment of other teams)

Figure 2: Course schedule and the essential skills to be acquired

3. Results

Figure 3 shows the students' rating for the question "Do you think (YES/NO) that lectures/projects have helped you increase your ability in (each skill)?" (Average results for % of YES in green for Lectures/hands-on exercises and in orange for Projects) and for the item "Rate your perception of your proficiency in each skill" (average result of the students' answer in % in purple). Results are ordered from the highest rated skill in Projects to the lowest. Our initial observation of the data indicates that students rated their own proficiency of almost every skill very high, the lowest value being 57%. They think they have gained or acquired these skills thanks to DEP or because they were proficient in them before they attended classes. It is also very interesting to note that the highest rated skills in Project (teamwork and time/work management) are rated lowest by Students' perception, which means that they feel that these are their weakest skills and they have improved them through the subject. On the contrary, those skills in which the students think they are strong (management of material resources and active learning) are rated lowest in Project and Lectures. They think they were strong in them before they attended classes and DEP has not helped them too much. Finally, the highest-rated skill in Lectures/hands-on exercises is communication (as well as time/work management) which shows that they thought both these sessions were very useful. The other skills that were equally rated are more difficult to interpret and their results are not so illustrative. In the future, it would be useful to carry out the survey at the beginning and at the end of the course, to clearly distinguish if the students think they were proficient in these skills before they attended classes or if they are proficient because they have attended classes.

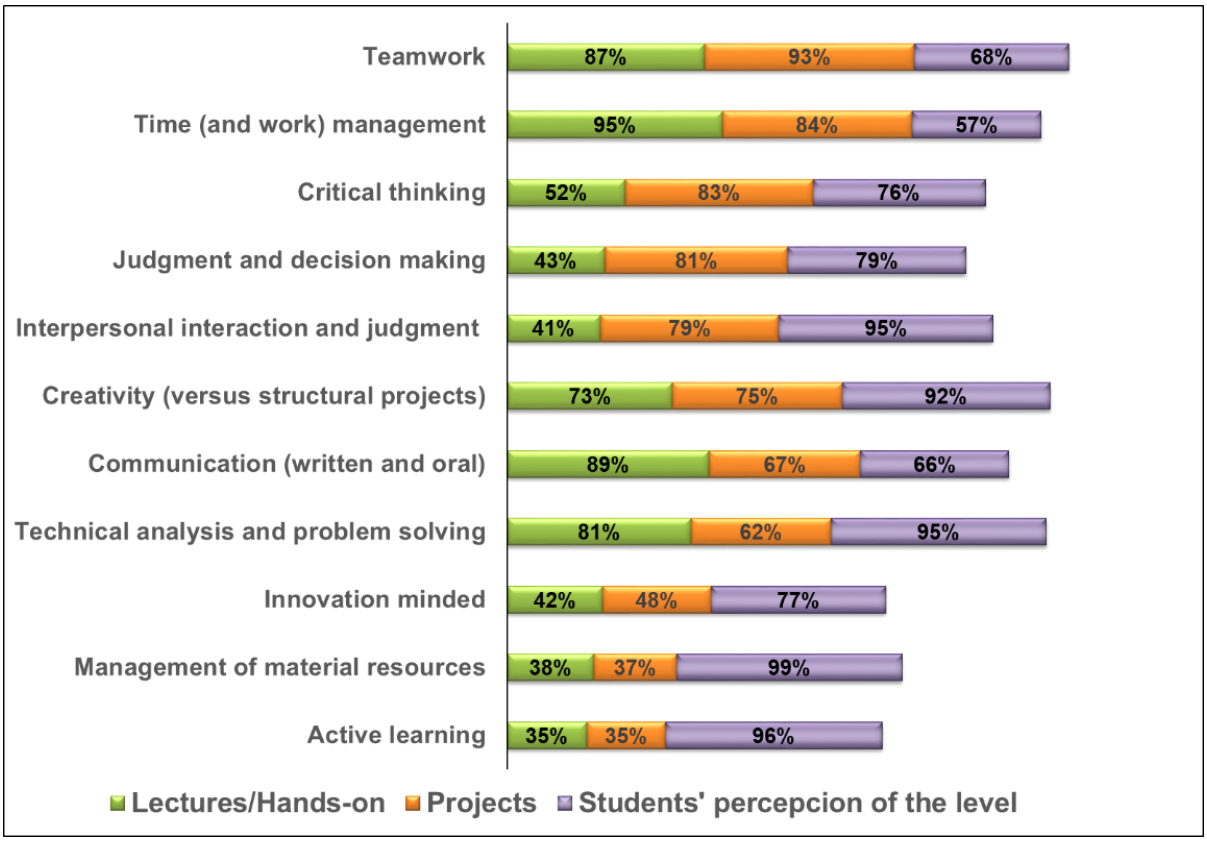

Figure 3. Students' rating of the usefulness of Lectures/hands-on exercises (green) and Projects (orange) for acquiring each skill. Own perception of their proficiency in each one (purple).

4. Conclusions

The use of PBL in the DEP subject has proved to be effective at promoting and enhancing some skills that are essential if a mechanical engineer is to succeed in a professional engineering context. The subject introduces students to the analysis and design of simple structures, and gives them a practical understanding of the main concepts of the strength of materials as applied to engineering systems. Its syllabus and teaching methodology (consisting of lectures, hands-on exercises and four practical projects) were specifically developed to provide the main skills that are regarded as being essential for a mechanical engineer (both technical/hard and soft skills). The results of a satisfaction survey have shown that students think that this teaching methodology has helped them acquire and reinforce skills like time/work management, communication and teamwork either through lectures and hands-on exercises or through each of the four projects carried out during the course. On the other hand, students think that their proficiency in skills like management of material resources or active learning are extremely good although this is not necessarily because they have attended the DEP subject.

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